4.1 Fysiologie van mariene dieren

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9.3 Gaseous exchange

Aerobic respiration requires organisms to obtain a supply of oxygen from the water and remove the waste carbon dioxide produced. This is traditionally known as gaseous exchange (but is also now often called simply gas exchange) and it occurs by the process of **diffusion**.

KEY TERM

Diffusion: the random movement of particles (or molecules) from a higher concentration to a lower concentration (down a concentration gradient); it is a passive process, not requiring the input of energy

Diffusion

Molecules are constantly moving in random directions. The energy of movement that they possess is known as kinetic energy. To understand diffusion, it helps if you look at a specific example (Figure 9.5). There is an uneven concentration of a molecule between two places, A and B. There is a concentration gradient between A and B, with a higher concentration in area A.

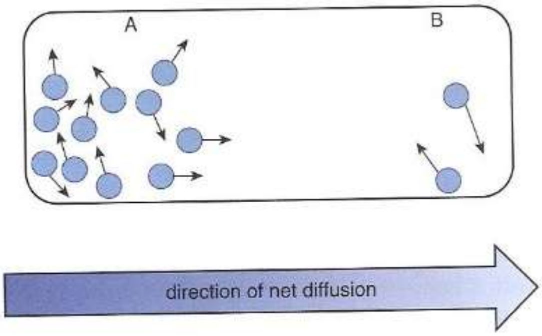


Figure 9.5. Net diffusion of particles from a high concentration to a low concentration. Particles move in random directions.

Because the molecules are all constantly moving in different directions, some of them will move from A to B. Because there are more molecules in area A, there is a higher probability that more of them will move from A to B than from B to A. There is a net diffusion of molecules from A to B. Eventually, the concentration in area A decreases and the concentration in B increases until the two areas are equal. When the two areas are equal, physical diffusion does not actually stop as the molecules are still moving. The rate of movement in both directions is approximately equal so that the net rate of diffusion is zero (Figure 9.6).

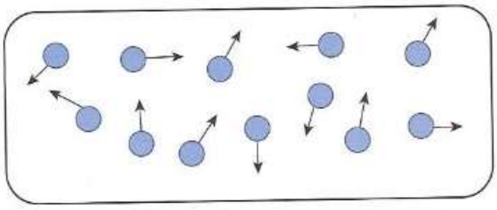


Figure 9.6. Particles are evenly spread and there is equal movement in both directions.

Diffusion is a passive process, requiring no additional input of energy, and is defined as the 'random net movement of particles from a higher concentration to a lower concentration'. It is a very important process by which many substances enter and leave the bodies and cells of organisms. The diffusion of gases in and out of cells and other tissues is affected by several factors, including:

- temperature
- concentration gradient
- distance moved
- surface area of exchange surface.

Temperature

Moving particles possess kinetic energy. As temperature rises, the kinetic energy of the particles rises so the particles move faster. If particles are moving faster, diffusion is faster.

Concentration gradient

A concentration gradient is the difference in concentration of a substance between two places, such as the difference in oxygen concentration between water and blood. The steeper or higher the gradient, the faster the rate of diffusion.

When cells are respiring, it is important to keep a higher concentration of oxygen outside the cells than inside. Respiration uses up the oxygen inside the cells rapidly, maintaining a low concentration inside. The result of this is that the oxygen concentration inside is kept lower than in the fluids outside the cells. There is always a difference in concentration between the inside and outside of the cell, so that oxygen diffuses into the cell. Carbon dioxide is being constantly manufactured inside the cell and is removed outside: the direction of the carbon dioxide gradient is the opposite of oxygen, ensuring a constant net diffusion out of the cell.

The maintenance of concentration gradients for gaseous exchange between blood and water is essential. Maintaining gradients is very important if diffusion is to be rapid, so organisms have evolved transport systems and ventilation movements to ensure delivery and removal of gases.

Marine organisms keep the concentration of oxygen in water higher than inside their blood by both moving the blood and by ventilation movements. Moving the blood brings fresh blood with a low oxygen concentration, and the ventilation movement brings fresh water with a high oxygen concentration.

Diffusion distance

To ensure rapid diffusion, the distance that the gases travel must be as small as possible. Gaseous exchange systems such as gills generally have very thin walls through which gases can diffuse rapidly.

Surface area

Most gaseous exchange organs, such as gills and lungs, have very large surface areas. If a surface area is large, the rate of gaseous exchange is high.

Gaseous exchange in marine organisms

Marine organisms have evolved a range of methods to ensure efficient gaseous exchange that take into account all the factors that affect rates of diffusion and the properties of water.

Water as a gaseous exchange medium

Carrying out gaseous exchange in water is more demanding than in air. The oxygen concentration in water is around 40 times lower than in the air, so gaseous exchange organs have to be highly efficient. The oxygen concentration is also highly variable and affected by both temperature and salinity, as shown in Figure 9.7. The higher the temperature and salinity, the lower the concentration of dissolved oxygen. Water is much denser and more viscous than air, so that moving it through the body of an organism requires more effort. This means that organs such as gills have an inlet and outlet aperture, whereas lungs require only one aperture through which air is breathed in and out.

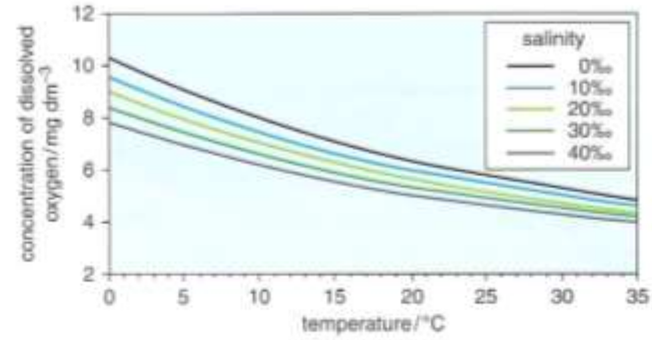


Figure 9.7. The effect of increasing temperature and salinity on the concentration of dissolved oxygen.

SELF-ASSESSMENT QUESTIONS

3 Explain why rapid respiration in a muscle cell would increase the rate of diffusion of oxygen from the blood into the cell and carbon dioxide out of the cell into the blood.

4 Global warming could lead to an increase in sea temperature and ice cap melting. Suggest and explain how this could affect the dissolved oxygen content of seawater.

Size and shape of marine organisms and gaseous exchange

In order to maximise gaseous exchange, organisms need to have a large surface area. As the size of organisms increases, both the surface area and volume increase, but not in a proportional, linear relationship. If you take a cube and increase the length of each side, the increase in volume is proportionally bigger than the increase in surface area. This is shown in Figure 9.8, where it is clear that the increasing size of the cube results in a much steeper increase in volume than surface area.

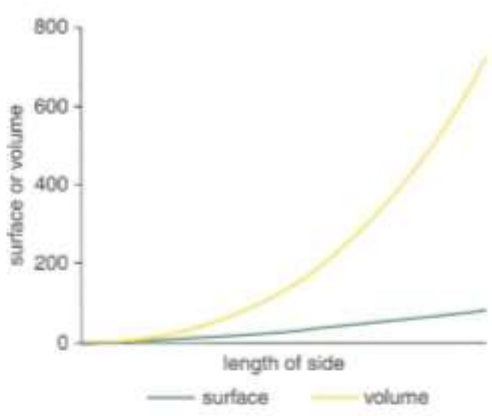


Figure 9.8. Effect of increasing the side length of a cube on the volume and surface area.

KEY TERM

Surface area : volume ratio an index that gives a relative measure of both surface area and volume; exchange organs generally have a very high surface area : volume ratio

In living organisms, having a higher surface area increases the rate of diffusion, but a higher volume tends to reduce the rate of diffusion as the distance to the centre of the organism increases. Larger organisms also have more cells so have a higher demand for oxygen. An index that takes into account both the surface area and volume of an organism is called the **surface area: volume ratio** and is calculated using the equation:

$$\text{surface area : volume ratio} = \frac{\text{surface area}}{\text{volume}}$$

- A higher surface area : volume ratio increases the rate of diffusion.
- A lower surface area : volume ratio decreases the rate of diffusion.

As spherical or cubic shapes increase in size, the surface area : volume ratio decreases (Figure 9.9). This means that the rates of diffusion of substances through the surface is lower. Protrusions from the surface (such as the tentacles of sea anemones) help to increase the surface area. This increases the surface area : volume ratio, making diffusion faster.

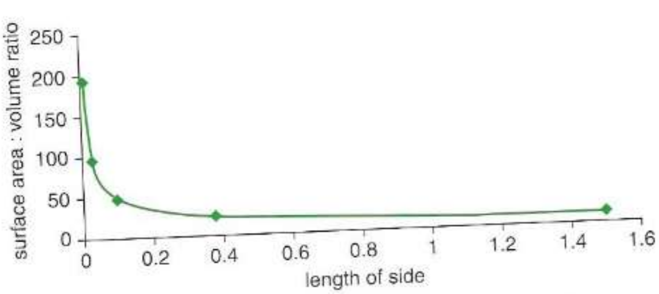


Figure 9.9. The effect of increasing side length of a cube on surface area : volume ratio.

The surface area : volume ratio of organisms affects their ability to carry out gaseous exchange. Very small organisms such as single-celled protozoa have high surface area : volume ratios so have a rapid rate of diffusion through their surface. They have no need for any specialised gaseous exchange organs as the surface area is sufficient for gaseous exchange and the diffusion distance is low. As the size of organisms increases, the surface area : volume ratio decreases and the surface of the organism is no longer sufficient for gaseous exchange. The distance from the outside of the organism to the centre over which gases would have to diffuse also becomes too great. Because of these problems, the majority of larger organisms have specialised gaseous exchange organs such as gills or lungs. Some larger organisms have shapes that increase the surface area and increase the surface area : volume ratio. Coral polyps and anemones have surface projections such as tentacles that increase the surface area : volume ratio.

The surface area : volume ratio is affected by both the overall size of an organism and its shape. More spherical organisms that minimise their surface area tend to have a low surface area : volume ratio, while those that are thinner with a very folded surface have a higher surface : volume ratio.

Circulatory systems

The use of specialised gaseous exchange organs brings with it the problem of how to transport gases. Circulatory systems evolved as a method of delivering oxygen to all tissues. In fish, blood that transports oxygen is pumped through a network of arteries, veins and capillaries by a heart. As in humans, the red blood cells of fish contain the protein hemoglobin, which binds reversibly to oxygen in the gills to form oxyhemoglobin. In areas such as muscles with low oxygen, the oxyhemoglobin releases the oxygen for respiration. The blood also transports dissolved carbon dioxide from the tissues to the gills.

$$\text{oxyhemoglobin} \underset{\text{gills}}{\overset{\text{tissues}}{\rightleftharpoons}} \text{hemoglobin + oxygen}$$

In a typical fish circulatory system such as that shown in Figure 9.10, blood travels in a particular route around the body.

- blood passes through muscles and other body tissues in capillaries, the smallest blood vessels, and releases oxygen and gains carbon dioxide
- blood is then returned to the heart in veins
- blood is then pumped out of the heart in arteries towards the gills

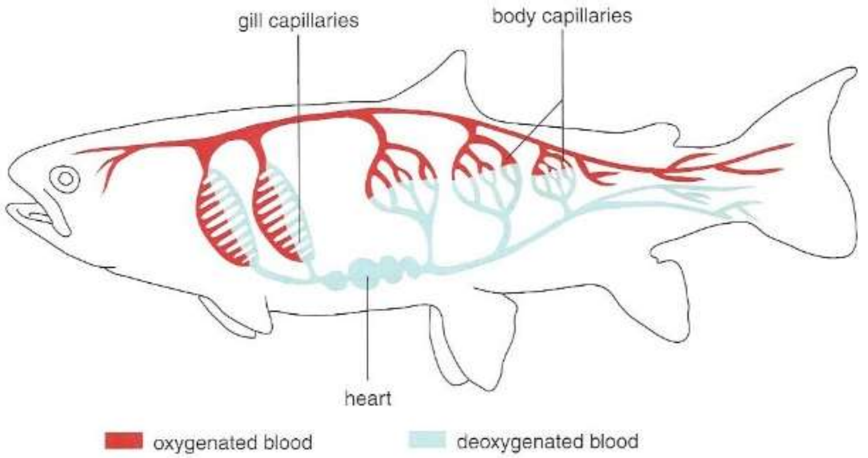


Figure 9.10. The circulatory system of a typical bony fish.

- as the blood passes through capillaries in the gills, it releases carbon dioxide into the water and gains oxygen
- blood leaves the gills in arteries and travels to the muscles in order to deliver oxygen and remove carbon dioxide.

Very active fish such as tuna require rapid respiration in the muscles, so blood is pumped quickly to the muscles. The circulatory system of these active fish is very efficient and maintains a high rate of blood flow.

Fick's Law and gaseous exchange organs

Gaseous exchange organs follow a rule know as Fick's Law. This states that the rate of diffusion of a substance is proportional to the product of the surface area of the organ and the diffusion gradient divided by the diffusion distance.

$$\text{diffusion rate} \propto \frac{\text{surface area} \times \text{concentration gradient}}{\text{diffusion distance}}$$

Fick's Law enables us to predict the following common features of all gaseous exchange surfaces:

- a large surface area
- steep concentration gradients of oxygen / carbon dioxide
- short diffusion distances.

Specific examples of gaseous exchange methods

Coral polyps

Coral polyps do not possess specialised gaseous exchange organs and all gaseous exchange takes place directly across the body surface by diffusion. The surface area : volume ratio of the polyp is sufficient because it has a large number of tentacles (Figure 9.11) and the thickness of the coral polyp epidermis is thin so that diffusion is rapid. Sometimes polyps move their tentacles to generate water currents refreshing the water around the polyp. This movement brings more oxygenated water into contact with the tentacles and maintains the diffusion gradients between the inside of the polyp and the water. Some coral polyps are able to pump oxygenated fluids between each other to ensure an even distribution of oxygen.

Fish gills

Bony fish such as groupers and tuna breathe by taking in water through the mouth, passing it over the gills and then forcing it out through gill openings (Figure 9.12). The gills are covered by a plate called an operculum that can open and close. On either side of the head are four pairs of gill arches, which are bony structures supporting the gills. The gills themselves are made up of many filaments, on the surfaces of which are folds called lamellae that are arranged at a 90° angle to the filaments. The filaments and lamellae provide a very large surface area to maximise gaseous exchange. The lamellae are very thin and contain an extensive capillary network. Blood circulates through

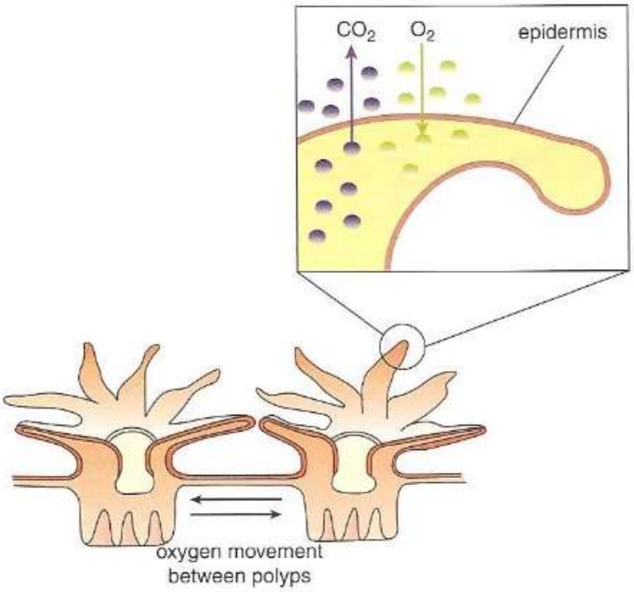


Figure 9.11. The structure of a coral polyp. The tentacles provide a large surface area and the epidermis is thin, reducing the diffusion path. Oxygen can move between polyps.

the capillary network and red blood cells pass through the capillaries very close to the external water, minimising the diffusion path. Pillar cells are found within the secondary lamellae, which help to slow the blood flow and press red blood cells to the surface of the lamella. Deoxygenated blood enters the gills through afferent arterioles and the oxygenated blood leaves through efferent arterioles to then travel to body tissues.

Fish of different species and ages have different gill surface areas according to their oxygen demand. Fast, active swimmers, such as tuna, mackerel and swordfish, have a high oxygen demand (and need to remove carbon dioxide rapidly) because the rate of respiration in the muscles is high. These fish have very large gill surface areas. Less active fish, such as sole and plaice, which often stay stationary for long periods of time, tend to have smaller gill surface areas. These fish move in shorts bursts in order to evade predators or catch food. The energy for this is often obtained by anaerobic respiration so the oxygen demand is lower.

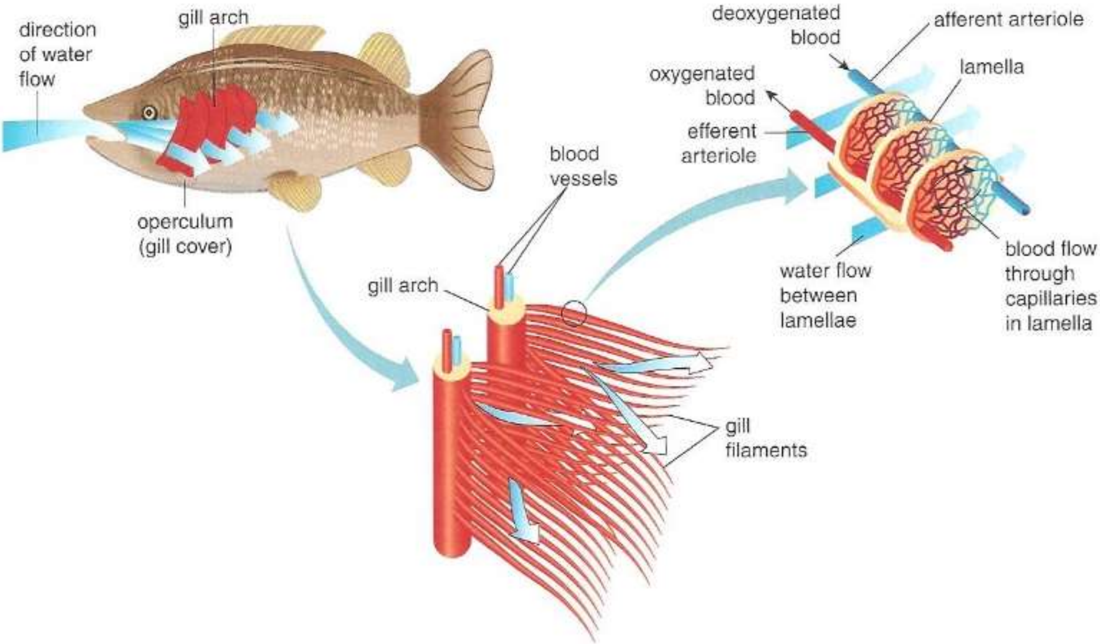


Figure 9.12. The gill structure of bony fish showing filaments, lamellae and direction of water flow.

Counter-current exchanger

Blood flows through the capillaries in the secondary lamellae in the opposite direction to the water. This arrangement is known as a counter-current mechanism. It ensures that gaseous exchange is highly efficient because the diffusion gradient is maintained across the whole gill surface.

If blood and water flow in the same direction, in a concurrent flow (Figure 9.13a), the diffusion gradient occurs until an equilibrium point when the concentration of oxygen in the blood and water is equal. In a counter-current flow (Figure 9.13b), the diffusion gradient is maintained along the full length of the gill so that diffusion is more efficient. In this way, oxygen diffuses into the blood along the whole length of the gill while carbon dioxide diffuses out into the water along the whole length of the gill.

Ventilation movements

In order to maintain the diffusion gradients of oxygen and carbon dioxide, water is constantly passed over the gills. Two different processes are used by fish to ventilate the gills: **ram ventilation** and **pumped ventilation** (Table 9.1).

ram ventilation	pumped ventilation
non-active pumping, saving energy	active pumping, using energy
can only occur when swimming	can occur during swimming and resting

Table 9.1. Differences between ram and pumped ventilation.

Ram ventilation

Fast-swimming fish such as tuna and sharks swim with an open mouth. As they swim, water is forced through the mouth, over the gills and out through the operculum or gill slits. There is no muscle contraction required by the muscles of the mouth and all the force for moving the water is generated by the forward motion of the fish. As no extra effort is made in pumping the water over the gills, energy is saved. One drawback is that fish that only use ram ventilation must keep swimming constantly in order to maintain a constant flow of water over the gills. Some fish species can switch back and forth between ram and pumped ventilation depending on their speed of movement. As fish swim faster, using more energy in their muscles, the rate of water flow over the gills automatically increases so that the rate of gaseous exchange increases. The rapid flow of water generated by high-speed swimming could potentially damage the delicate gill structures. In order to prevent this damage, the gill arches are often reinforced or fused together in tuna species.

KEY TERMS

Ram ventilation: ventilation of gills by swimming with the mouth open so that a constant flow of water passes through the mouth and over the gills; it only occurs when a fish is swimming

Pumped ventilation: ventilation of gills by the muscle action of the mouth pumping water over the gills; it can occur when the fish is stationary

Pumped ventilation

The majority of fish actively pump water over their gills. This means that even when a fish is stationary, there is a constant flow of water over the gills. Fish that use this method use the muscles of the buccal cavity (mouth region), which requires energy so can be energetically costly. The benefit of pumped ventilation, however, is that fish can continue to breathe when not moving so can remain in one place for extended periods of time. When the fish swim faster, the oxygen demand increases and the rate of pumping also increases.

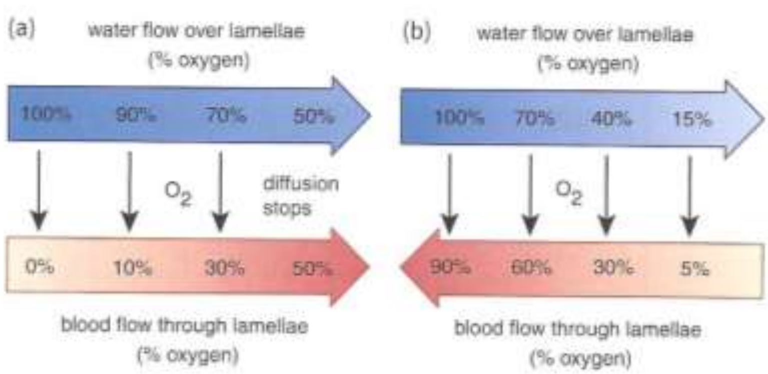


Figure 9.13. (a) A concurrent flow of blood and water and (b) a counter-current flow of blood and water.

When considering pumped ventilation, it is a good idea to remember:

- water always flows from an area of higher pressure to an area of lower pressure
- as the volume of a cavity increases, the pressure decreases, and vice versa.

Figure 9.14 shows the stages of water flow through the buccal cavity of a bony fish.

During inflow of water:

- the mouth opens
- the volume of the buccal cavity is increased by muscle contraction and relaxation
- this lowers the pressure inside the buccal cavity to below the external pressure
- water flows into the buccal cavity down a pressure gradient
- the operculum closes as water tries to flow back across the gills.

During outflow water over the gills:

- the mouth closes
- the volume of buccal cavity is reduced by muscle contraction and relaxation
- pressure inside the buccal cavity rises above the external pressure
- water flows over the gills and the operculum is forced open, allowing the outflow of water.

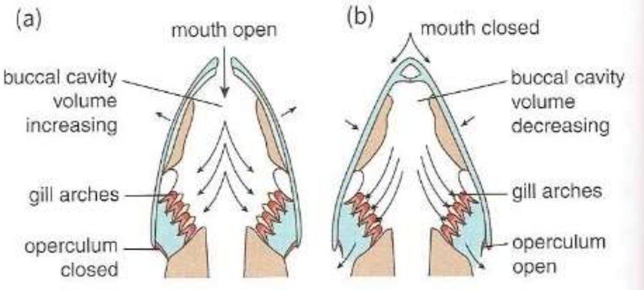


Figure 9.14. Movement of water across gills seen from above. (a) Mouth open, buccal cavity chamber increases in volume, water is drawn into the buccal cavity, operculum is closed; (b) Mouth closed, buccal cavity chamber reduces in volume, operculum opens and water flows over gills.

Gaseous exchange organs of different species all obey Fick's Law (Table 9.2).

SELF-ASSESSMENT QUESTIONS

5 Draw up a table to show the different methods of gaseous exchange used by coral polyps, tuna and grouper, and the advantages and disadvantages of each method.

6 Explain the following.

a Highly active fish die more frequently then less active ones when the temperature of the water rises very high.

b Gill parasites that eat away parts of the gill lamellae reduce the growth rate of farmed salmon.

c If fish are removed from water, they suffocate as the gill lamellae collapse and stick together.

species	gaseous exchange surface	large surface area	short diffusion path	maintenance of diffusion gradient
coral polyp	body surface	large numbers of tentacles	thin epidermis on body surface	none, although tentacles may move
grouper	gill	gill filaments and secondary lamellae	thin epidermis on gills	blood flow through capillaries, pumped ventilation
tuna	gill	gill filaments and secondary lamellae	thin epidermis on gills	blood flow through capillaries, ram ventilation
shark	gill	gill filaments and secondary lamellae	thin epidermis on gills	blood flow through capillaries, ram ventilation

Table 9.2. Summary of how gaseous exchange organs of different species obey Fick's Law.

9.4 The regulation of salinity

Different bodies of water often have different salinities that may vary both over short and long periods of time. For example, the Red Sea has a very high salinity and the salinity of the Baltic Sea is very low. Estuaries and areas near the outflow of rivers often have brackish water that has a low salinity. In order to survive in media that can have a range of salinities, organisms must possess physiological adaptations.

KEY TERMS

Osmosis: the movement of water from a higher water potential (more dilute solution) to a lower water potential (higher concentration of solute) across a selectively permeable membrane

Water potential: a measure of the potential energy of water in a solution and thus the tendency of water to move from one place to another; the more solute that is dissolved in a solution, the lower the water potential

Osmosis

Osmosis is a process that is of vital importance to all organisms. It is defined as the net movement of water molecules from a region of higher **water potential** to a region of lower water potential across a selectively permeable membrane.

Water potential is a measure of the potential energy of the water molecules in a solution. The more water molecules in a solution, the higher the water potential. If a solute such as salt is dissolved in the water, the proportion of water molecules in the solution decreases so the water potential falls.

In simple terms, the higher the concentration of solutes, such as salt in a solution, the lower the water potential. The highest water potential possible is that of pure water.

If you place two different salt solutions next to each other, separated by a selectively permeable membrane (Figure 9.16), water molecules will move from the weaker, more dilute solution to the more concentrated one.

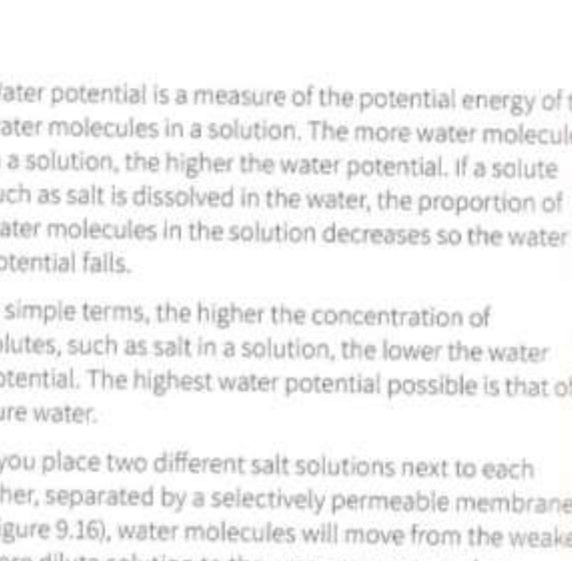


Figure 9.16. Movement of water by osmosis from a dilute solution to a concentrated one.

Certain terms are used to describe solutions that have higher or lower water potentials compared with the cells and body fluids of an organism.

- Hypertonic solutions have a lower water potential. They have a higher concentration of solutes and will tend to draw water out of cells.
- Isotonic solutions have a water potential that is equal to the cells. They have an equal concentration of solutes and will result in no net movement of water.
- Hypotonic solutions have a higher water potential. They have a lower concentration of solutes and will tend to pass water into cells.

In living organisms, changing the salt concentration around cells can result in water entering cells or leaving them, causing extensive damage. Organisms such as plants and algae possess cell walls so, if water passes into the cells, the cells will not burst. Animal cells, however, do not possess cell walls and if too much water passes into them, they will burst.

SELF-ASSESSMENT QUESTIONS

7 Rearrange the following in order of increasing water potential: pure water, 2 mol dm^{-3} sodium chloride solution, 1.5 mol dm^{-3} sodium chloride solution, 0.2 mol dm^{-3} sodium chloride solution.

8 Use your knowledge of osmosis to explain why:

- **a** placing limp vegetables into pure water can 'firm them up'
- **b** sprinkling sugar on the surface of fruit produces a syrup
- **c** covering fish with salt preserves it from decay.

Marine organisms usually live in an environment with high salinity and low water potential. This means that there is a danger of water loss from their bodies into the surrounding water. Some organisms are able to survive only in a narrow range of salinities and are classed as **stenohaline** species. Species such as salmon, which are able to tolerate a wide range of salinities, are classed as **euryhaline** species.

Osmoconformers

Osmoconformer organisms have an internal water potential of cells and body fluids that is equal to that of the surrounding water. This means that their fluids are isotonic to the water and there is no net gain or loss of water. The majority of osmoconformers are stenohaline invertebrates and are thus not resistant to major changes in external salinity.

Mussels are euryhaline osmoconformers and frequently live in estuarine areas where the salinity of the water may be very variable. They are able to survive there by using two methods.

- When salinity changes, mussels close their shells tightly to prevent the seawater coming into contact with their body tissue.
- They can increase and decrease the solute concentrations of their cells if the external salinity changes. The solute concentration is matched to the external water so that no net in- or out-flow of water occurs.

Despite some degree of control over **osmoregulation**, most mussel species tend to be restricted to a particular range of salinities. Some species are restricted to brackish waters of estuaries while others are restricted to the more saline waters of the sea.

KEY TERMS

Stenohaline: description of organisms that are able to tolerate only a narrow range of salinities

Euryhaline: organisms, such as salmon, that are able to tolerate a wide range of salinities

Osmoconformer: organisms that have an ionic and salt concentration that is the same as the surrounding water

Osmoregulation: the process of regulating the internal water and ion content of an organism

Osmoregulator: organisms that regulate their internal salt and ion balance at a constant level, which may differ from the surrounding water

Osmoregulators

Osmoregulators maintain a constant internal osmotic pressure that may differ from the environment they are in. The majority of bony fish species are stenohaline osmoregulators that can only live in a narrow range of salinities. They actively maintain a particular salinity in their cells and body fluids.

Marine fish

In most seas and oceans, the water surrounding fish has a higher salinity (hypertonic) than the cells and body fluids. Water is drawn out of the body from the gills and skin by osmosis and salt diffuses into the body from the water. This constant loss of water could lead to dehydration, resulting in cell damage and death. In order to prevent excess water loss, marine bony fish carry out several processes.

- They constantly drink seawater to replace water that is lost by osmosis.
- Sodium and chloride ions are actively secreted by the gills. Specialised cells on the gill filaments have protein 'pumps' in their membranes that pump the ions into the water, which requires energy in the form of ATP.
- Magnesium and sulfate ions are actively secreted by the kidney into the urine.
- Reabsorption of water by the kidney produces a low volume of very concentrated urine.

These processes are summarised in Figure 9.17.

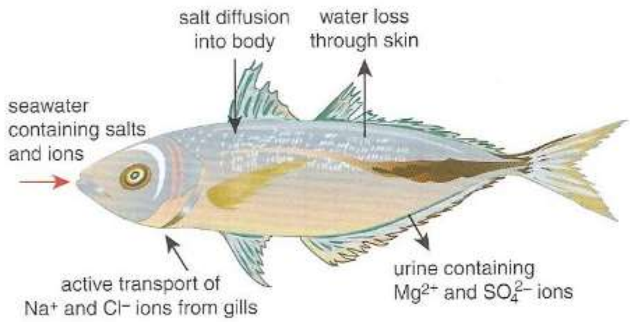


Figure 9.17. Osmoregulation by marine fish.

Active transport

Active transport is the pumping of substances (often ions) across a membrane by living cells against a concentration gradient. It is carried out by specialised membrane proteins that use the energy in ATP to move the ions against the concentration gradient. Because it requires energy, it can only take place in living, respiring cells.

Fresh-water fish

Fish species that live in fresh water have the opposite problem to marine fish. Fresh water has a very low salinity and high water potential (hypotonic). Water constantly enters the body through the gills and skin by osmosis (Figure 9.19). In order to prevent excess water loss, fresh-water bony fish carry out several processes.

- They drink small amounts of water.
- The gills actively pump sodium and chloride ions into the blood and body fluid. Specialised cells have protein pumps that actively pump the ions from the external water to the internal body fluids. These pumps use ATP, similar to the pumps in marine fish.
- They produce large amounts of very dilute urine.

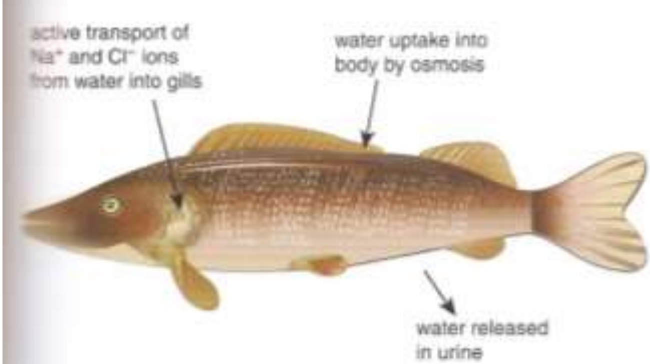


Figure 9.19. Osmoregulation in fresh-water fish.

Euryhaline fish

Euryhaline osmoregulatory species, such as salmon and eels, are able to live in a wide range of salinities, from the fresh water of rivers to the salt water of the oceans. They are able to change direction of ion pumping depending on the salinity of the surrounding water (Table 9.7).

When in salt water, the surrounding water is hypertonic to their body fluids. Salts are pumped out of the gills and they drink water to replace the water that has been lost by osmosis.

When in fresh water, the surrounding water is hypotonic to their body fluids. The ion pumps move the salts in the opposite direction, taking salts into the blood.

	salmon body fluid	ocean water	fresh water
solute concentration / %	1.0	3.5	<0.1

Table 9.7. Comparison of salinity in salmon body fluids, ocean water and fresh water.

SELF-ASSESSMENT QUESTIONS

9 Summarise the osmoregulatory mechanisms a salmon uses as it moves from river water to the sea.

10 Draw up a table to compare diffusion, osmosis and active transport (think about facts such as the direction of movement, the need for energy, the substances moved and the need for a membrane).

Opdracht bij les 4.1

- Case study: De Aral Zee

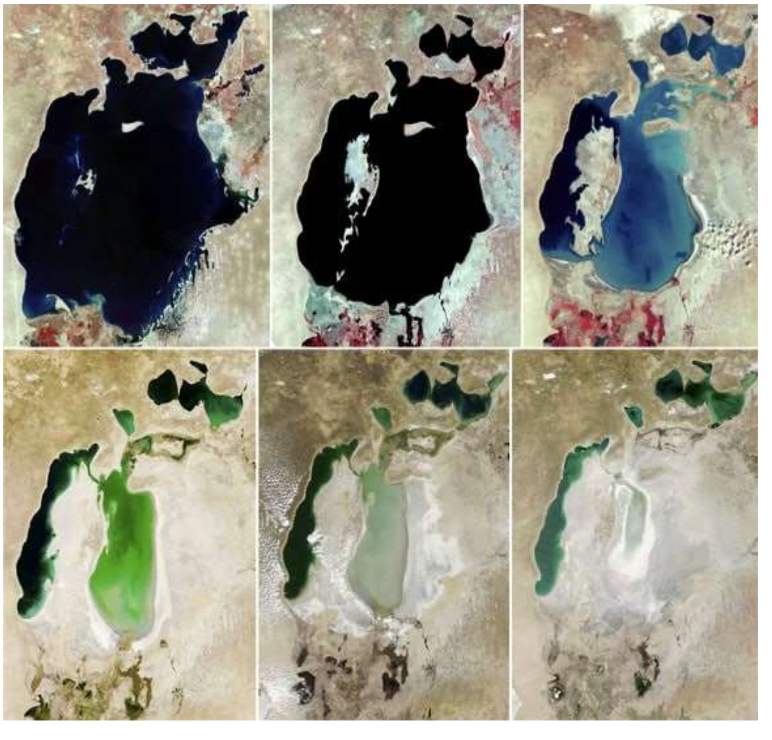
Les 4.1 - De Aral Zee, een ecologische catastrofe

De Aral Zee is een meer in Centraal Azië op de grens van Kazakhstan en Oezbekistan. In 1960 was het het op drie na grootste meer ter wereld, met een oppervlakte van 67.499 vierkante kilometer. Het was een licht zout meer met een gemiddelde saliniteit van 10 g/dm3 en werd gevoed door twee rivieren, de Amu Darya in het zuiden en de Syr Darya in het oosten. Er konden tenminste 12 verschillende soorten vis en 160 soorten ongewervelden worden gevonden. In de jaren zestig werd besloten om de rivieren om te leggen zodat er een irrigatie netwerk kon worden aangelegd. Meer dan 30.000 kilometer kanaal, 45 dammen en meer dan 80 reservoirs werden gebouwd om de woestijn te irrigeren voor landbouw, en dan voornamelijk de productie van katoen en tarwe. Het irrigatie systeem was slecht gebouwd waardoor tot wel 75% van het water verloren ging in lekken en door verdamping.

Tussen 1961 en 1971 werd het waterniveau in de Aral Zee elk jaar 10 centimeter lager. De visserijen kwamen in de problemen doordat de vis begon te verdwijnen. In de jaren tachtig zakte het waterniveau met gemiddeld 90 centimeter per jaar en uiteindelijk brak de Aral Zee op in twee delen, de Noordelijke en Zuidelijke Aral Zee. In 1998 was het totale oppervlakte van de nu twee zeeën nog maar 28.687 vierkante kilometer, met meer dan 80% afname in volume. De saliniteit was gestegen naar 45 g/dm3 (zeewater ligt meestal rond de 35 g/dm3). Veel van de oorspronkelijke vissoorten, zoals karper, en de ongewervelden waren compleet uitgestorven en vervangen door mariene en euryhaline soorten zoals bot.

In 2004 was het totale oppervlakte van de Aral Zee nog maar 17.160 vierkante kilometer, 25% van de originele grootte, en de saliniteit die vijf keer zo hoog was geworden had bijna alle oorspronkelijke soorten gedood. Veel van de geïntroduceerde soorten raakten ook uitgestorven, omdat ze de hoge saliniteit niet konden overleven.

De overheid van Oezbekistan vond het verlies van de Aral Zee het waard vanwege de productie van katoen. Een van hun onderzoekers noemde de zee ‘een foutje van de natuur’ en ‘een nutteloze verdamper’. Er wordt jaarlijks meer dan 1 miljoen ton geproduceerd en beslaat ongeveer 17% van Oezbekistans export. De industrie zelf is wel controversieel. Er wordt gebruik gemaakt van gedwongen werkkrachten, inclusief kinderen vanaf 9 jaar.



In 2003 is de overheid van Kazakhstan begnnen met een project om de Noordelijke Aral Zee te herstellen. Een grote dam werd gebouwd om de Noordelijke en Zuidelijke Aral Zee te scheiden, zodat het water vanuit het noorden niet verloren zou gaan aan het zuiden. De dam was af in 2005 en sindsdien is het waterniveau van de Aral Zee langzaam aan het stijgen, en de saliniteit daalt. In 2006 was de saliniteit terug naar waarden die normaal zijn voor een riviermonding en een aantal oorspronkelijke vissoorten kwamen terug. Ironisch genoeg leidde dit tot een afname van de vis verkoop omdat mensen de voorkeur gaven aan mariene soorten. Helaas is de Zuidelijke Aral Zee inmiddels gekrompen tot 10% van de oorspronkelijke grootte, en de saliniteit is meer dan 100 g/dm3. Er leven geen vissen meer, omdat zelfs voor mariene soorten de saliniteit te extreem is. Een aantal ongewervelden kunnen hier overleven, maar niet veel meer.

Er zijn een aantal consequenties aan het verlies van de Aral Zee:

- Ecologisch. De Aral Zee is nu bijna een dode zee. Er zijn geen vissen meer, en bijna geen ongewervelden. Soorten die vis in hun dieet hadden worden bedreigd. Er leefden 173 diersoorten in het gebied, nu zijn dat er minder dan 38.

- Gezondheid. Giftige stofstormen die een hoge concentratie zout bevatten komen veel voor. Dit heeft geleid tot ademhalingsproblemen, lever-, nier-, en oogziekten. Kindersterfte is hoog, met 75 doden voor elke 100 geboortes. Het verlies van vis en voedsel als gevolg van het gebrek aan zoet water en het afzetten van zout op het land heeft geleid tot voedselgebrek en ondervoeding.

- Economisch. De Aral Zee visserijen zorgden eerst voor 40.000 banen en een groot gedeelte van de totale visvangst. Deze industrie is nu bijna helemaal verdwenen. Er is veel werkeloosheid, wat weer leidt tot armoede en verlies van de populatie doordat mensen het gebied verlaten.

1. Vat samen hoe menselijk handelen heeft geleid tot het verlies van de Aral Zee.

2. Verklaar de verandering in saliniteit door de jaren heen.

3. Verklaar waarom stenohaline vissoorten uitgestorven zijn in de Aral Zee.

4. Verklaar waarom mariene euryhaline vissoorten beter konden overleven in de Aral Zee.

5. Evalueer de impact van de katoenindustrie in Kazakhstan en Oezbekistan.